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A Laboratory Study on Wave Reduction by Mangrove Forests

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Abstract

The 2004 Indian Ocean Tsunami has caused severe damage to African and Asian countries especially western coast of Thailand and Sri Lanka. However, it was noticed that the villages situated behind mangrove forests were protected from tsunami damage compared to nearby exposed villages in southeastern India. Since then, more countries have started to replant mangroves for coastal protection. Extensive researches have been carried out to study the performance of mangrove forests in wave reduction. However, the quantitative effects of mangrove vegetation characteristics are still poorly understood. Hence, this study aimed to quantify the wave height reduction with various mangrove densities as well as to study the influence of tree arrangements on wave reduction. The laboratory experiments were conducted in a narrow wave flume using artificial mangrove models. The results showed that the wave height reduction in area with mangroves was about two times larger compared to that in bare land. The wave reduction difference between tandem and staggered arrangements of trees was less than 10 %. It is also found that the 80 m wide *Rhizophora* forest is sufficient to reduce wave height by 80 %.

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Keywords: Laboratory experiment, Mangroves, Rhizophora, Tree arrangement, Tsunami, Wave reduction

1. Introduction

The importance of mangrove forests came to light after the 2004 Indian Ocean Tsunami. A total of five villages including two on the coast and three behind mangroves in southeastern India were examined. It was found that villages on the coast were completely damaged while areas shielded by mangroves located at the same distance from the coast experienced no destruction [1]. The World Conservation Union (IUCN) compared the damage level in Sri Lanka and reported that two people died in the area with dense mangroves

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while 6000 people died in the area without vegetation, comparatively [2]. Mangroves probably did not completely shield the areas of maximum tsunami intensity from substantial destruction; however, in less hard hit areas by tsunami, the damages were significantly reduced in areas where mangroves were present. Recently, many countries have started to replant mangroves for coastal protection. Extensive researches have also been undertaken to study the performance of mangroves in wave attenuation. However, the quantitative effects of mangrove vegetation characteristics on wave reduction are still poorly understood.

2. Factors Influencing Wave Reduction Rate in a Mangrove Forest

2.1. Species

The capability of a mangrove forest to dissipate wave energy is very much dependent on its species composition [3, 4]. The *Rhizophora* spp. and *Pandanus odoratissimus* were most effective in wave attenuation [4]. The attenuating capability of *Rhizophora* trees is perhaps due to its complex aerial root structures that create greater friction to incoming waves [5, 6]. The 50 m wide *Avicennia* forest is adequate to reduce wave height from 1 m to 0.3 m [7] whereas 100 m wide *Sonneratia* forest can reduce wave energy up to 50 % [3].

2.2. Density

Dense mangroves attenuate more waves than less dense mangroves [3, 5, 8, 9]. Mangrove forest density and its intricate root structure were deemed to be important by some researchers based on mathematical developed models [8, 10], direct observation [7, 11] and site measurement [5]. [12] found that wave-trunk interactions dominated in a dense mangrove forest while wave breaking dominated in a less dense forest, and these two mechanisms have significant effect on wave reduction rate.

2.3. Band width

The optimum mangrove forest width for coastal protection relies on mangrove species, density and characteristics of the area. Some Asian countries have delineated the minimum required mangroves width for coastal protection. A mangrove belt ranging from 500 m to 1000 m has been set as a buffer zone along the Mekong delta coastline, Vietnam [13]. The mangrove buffer width in Philippines is 20 m and can reach up to 50 m in storm prone areas. In Malaysia, the 1950s regulation delineated 200 m wide mangrove forest to protect agricultural land [7].

2.4. Age

The age of a mangrove tree denotes the height of the tree, the trunk and root diameters as well as stems density. The resistance to wave damage is higher when the mangrove tree is older and bigger [3, 7, 8, 11, 14]. This is parallel with the findings by [9] that the wave reduction rate was affected by the age of the mangrove. When the mangrove trees were 5 to 6 years old, the wave reduction rate was large due to the better developed mangrove plants that exerted larger drag force to incoming waves. While in the area of 6 months-old mangroves, the wave reduction rate was small because the mangrove forest was still young and sparse.

3. Experimental System

The size of a *Rhizophora* tree of about 20 years old was scaled down by a factor of 10. The laboratory experiments were conducted in a narrow wave flume in Offshore Laboratory of Universiti Teknologi PETRONAS. The wave flume was 23 m long, 1.5 m wide and 1.2 m high. One wave gauge was placed before the slope and 10 wave gauges on the flat platform to measure the wave heights in the vicinity of the mangrove field as shown in Fig 1.

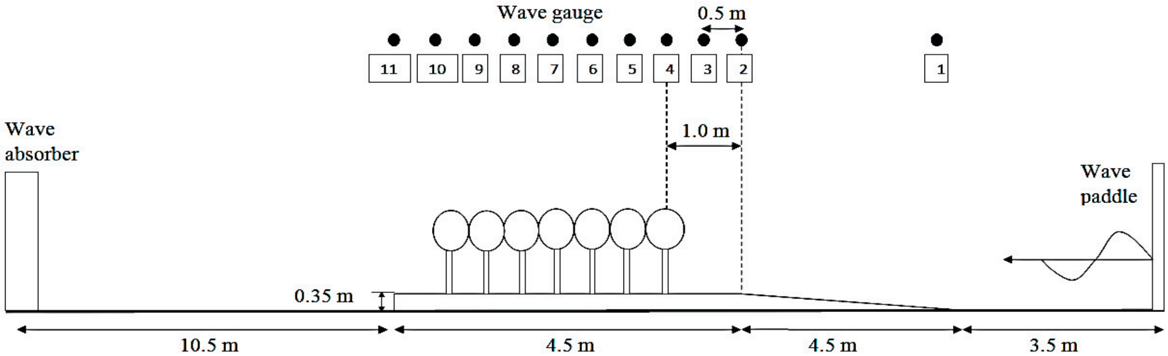

Fig. 1. Schematic of narrow wave flume setup

4. Test condition

4.1. Comparison between tandem and staggered arrangements of trees

The mangrove models were arranged in tandem order where there were gaps between rows of trees. For staggered arrangement, the trees were arranged in such a way that the gaps between the trees were blocked by the trees behind them (Fig 2). The water depth was 0.15 m and wave height was 0.05 m.

Fig. 2. Test for tree arrangements

4.2. Comparison between densities

Three cases representing densities of naturally grown and replanting mangroves were tested, which are 11 trees/m² (sparse), 16 trees/m² (median) and 22 trees/m² (dense). Water depth and wave height were 0.15 m and 0.07 m, respectively.

5. Results and Discussion

The wave heights decreased when the waves propagated further into the mangrove field. For a 50 m wide *Rhizophora* forest, the wave reduction was over 52 % compared to 29 % by bare land which is nearly two times larger (Fig 3a). The wave reduction in bare land was mainly caused by the bottom friction. For area with mangroves, there was an additional friction contributed by the mangrove trunks and root system, hence imposing higher resistance to incoming waves. It is also shown that the wave reduction was greater when the mangrove models were arranged in staggered order compared to tandem. For 100 m wide mangrove forest, the wave reduction for tandem and staggered arrangement of trees were 78 % and 85 %, respectively (Fig 3a). For the case of staggered arrangement, the waves could not propagate freely through the gaps between mangrove trees, hence more wave energy was dissipated. However, the difference in wave reduction for both arrangements was less than 10 %, which is not significant. This might be due to the structure of *Rhizophora* roots which spread widely and in most cases overlap with roots of other trees. Since most of the waves were attenuated by the *Rhizophora* roots, the wave reduction was still considerably high regardless of the tree arrangement (tandem or staggered order).

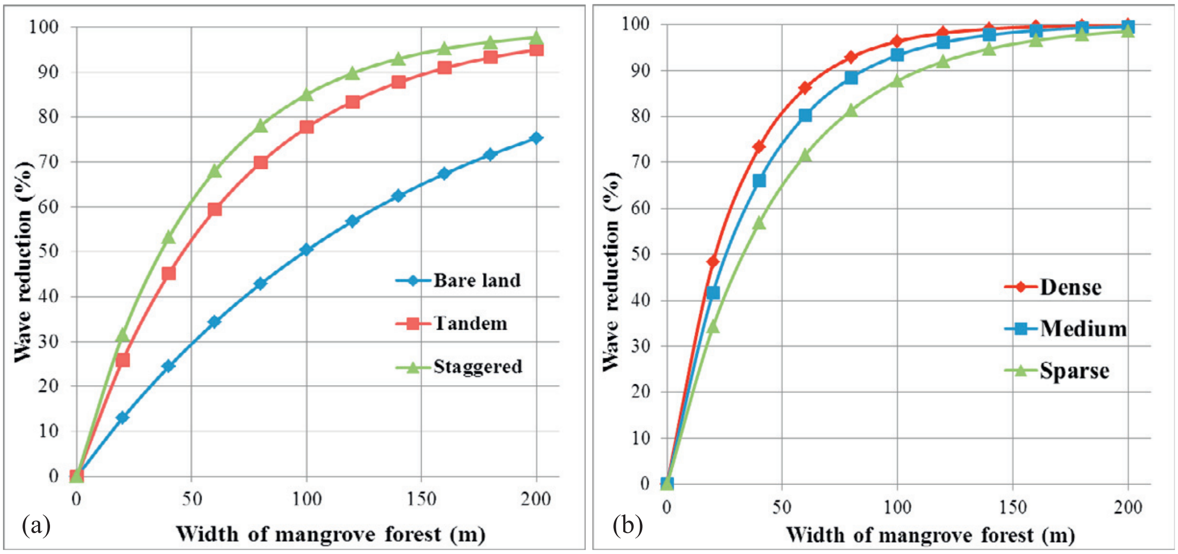

Fig. 3. (a) wave reduction (%) across bare land, mangrove forest of tandem and staggered arrangements; (b) wave reduction across mangrove forest of different densities (dense = 0.22 trees/m², medium = 0.16 trees/m², sparse = 0.11 trees/m²)

Dense mangrove forest attenuated waves more effectively. The wave reductions caused by dense, medium and sparse densities across 50 m wide mangrove forest were 81 %, 74 % and 65 %, respectively (Fig 3b). The tree spacing was smaller in a dense forest, hence imposed higher resistance to the incoming waves due to larger quantity of trunks and roots available per unit area. The density of 22 trees/m² represented a tree spacing of 2.0 m in reality. In fact the distance between *Rhizophora* trees are seldom less than 2.0 m because the prop roots spread wide enough that take up lots of space. In Larut Matang, Perak, *Rhizophora apiculata* and *Rhizophora mucronata* are planted at the spacing of 1.2 m and 1.8 m, respectively. However, the thinning will be done at later time to provide enough space for growing. The wave reductions were considerably high for all three densities due to the intricate and prop roots of *Rhizophora* trees. It is found that the 80 m wide mangrove forest of density 0.11 trees/m² is sufficient to reduce wave height over 80 %.

6. Conclusion

The mangrove forests are proven to be effective in surface wave attenuation. The wave reduction for area with mangroves is about two times larger than area without mangroves. In area protected by mangroves, the wave impact on shore is minimal. This is particularly important to mitigate erosion problem as high waves could wash away the soil, causing retreat of the coastline. The arrangement of the mangrove trees did not exhibit significant effect on wave reduction with difference of less than 10 %. In fact, both arrangements generated high wave reduction. This indicates that arrangement of mangrove seedlings is not of great concern during mangrove replanting project. A mangroves width of 80 m with density of 0.11 trees/m^2 is sufficient to reduce wave height by 80 %. During normal day, the mangrove forest reduces the impact of waves on shore and it is the most natural and cheapest way for coastal protection. Thus, the mangroves re-planting effort along the coast should be continued, perhaps in a more structured way, in the areas that are vulnerable to the impact of waves.

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